A History of Wave Energy

by

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ABSTRACT

The following text is based almost entirely on government select committee reports, and other associated publications, on wave energy.

It attempts to provide a complete picture, historically, of the wave energy programme. Although work has been done before 1973 and in other countries, the text is mainly concerned with the expansion and development of the programme in the U.K., since this date.

It introduces the people and devices involved, and attempts to show the influence of the Government and the Civil Service upon them.

It highlights the problems of funding research and development of alternative energy schemes, and looks at the possible contribution that this particular method of producing energy could make.

In conclusion it looks at the possible future development, or otherwise, of the programme.

As it is not a very technical report, I hope that it may be readily understood by those not familiar with the subject, and yet provide informative and interesting reading for those more expert.

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INTRODUCTION

When you first come across the idea of producing energy from the waves, it seems marvellous.
We are surrounded by waves, they go on forever, and they come in free.
The sea is at its roughest in winter, therefore producing more energy just when we need it most.
We could obtain electricity without pollution and without burning up precious coal and oil, and never run out of fuel.
The idea of harnessing the waves is not new, the first ever design was patented in 1799. However, no one has yet succeeded in producing a large scale working device, probably the most useful idea being produced by the Japanese in the form of a navigation bucy.

It took the gigantic leap in oil prices in the early 70's, coupled with the miners strikes to make people aware of their dependance on these fuels, and rekindle interest in new energy sources.

The Governments interest was officially declared in 1974, with the publication of a report by the Central Policy Review Staff. This led to the initiation, by the newly formed Department of Energy, of a detailed introductory assessment of large scale generation of electricity from ocean waves, by the National Engineering Laboratory, East Kilbride.

The amount of energy that could be produced from the waves has been estimated, even by the most sceptical, as about 25% of the Central Electricity Generating Boards annual electricity output. Even allowing for shipping lanes etc. an average of 7,000 MW of electrical power (or 60 TWh a year) could be supplied.

There is the prospect of using the spare capacity in our empty shipyards, as the skills found there are just the ones required to build the structures needed to produce energy from the waves.
However, against this optimism rises a cloud of financial objections, primarily against manufacturing and maintenance costs. The costs of manufacturing fully operational units is considered to be inordinately high, although they would by necessity be modular and constructed according to budget, and high maintenance costs would be incurred due to the very nature of the element whose power it is intended to harness. Other problems incurred are problems associated with mooring floating units in heavy seas, and the ultimate transmission of the harnessed energy to the consumer.

Hopefully research and devlopment will reduce costs in the future and help overcome these problems, and eventually lead to the building of a full scale, working device in the seas off the U.K.

1. What Is A Wave?

The earth receives immense amounts of solar energy each year. This energy generates winds, which in turn generate the waves by blowing over the oceans of the world.

The amount of energy in the waves is governed by two main factors

1. The strength of the winds.
2. The fetch, or the uninterrupted distance over the oceans, that the wind can blow.

Wave power potential world wide, can be related to the distribution of the winds.

In both the northern and southern hemispheres the strongest winds are located between latitudes 40° and 60°, the equatorial regions being comparitively free of winds and the polar regions either ice bound or continental. Due to the rotation of the earth the highest concentrations of wave energy are on the eastern sides of the oceans in the main wind belts, these being the downward end of the fetches. From this it can be seen that with respect to the potential availability of wave energy, the U.K. is situated in an ideal position, being on the eastern side of the Atlantic Ocean and in the ideal latitude.

The annual average energy in a wave out at sea is around 50kW/m, and the waves are at their largest and most energetic in the winter months when demand for energy in the U.K. is at its greatest.

In principle the waves reaching our coast from the North Atlantic could satisfy a considerable fraction of our electricity demand provided that reasonably high overall conversion efficiencies can be achieved by wave energy devices.

'Station India' 400 km out towards Iceland gives figures of around 100 kW/m as an average of wave power available over the whole year, way out in the Atlantic. These power levels can rise to 600kW/m in winter and in severe storms can sometimes exceed 5 MW. However as I have already stated, by the time waves reach what are considered to be prime world sites for the converters (e.g. South Uist, Outer Hebrides) the annual average available power has fallen to 50kW/m.

The amount of energy available which a device can extract from the waves varies, not only with its distance out at sea but also with the depth of water in which it is sited.

For example; N.E.L. measurements of annual average available power crossing three such points gave the following data.

Depth of Water	Distance from Mainland	Available Power
15 m	4 km	17 kW/m
22 - 25 m	6 km	32 kW/m
44 m	20 km	48 kW/m

The proportion of this available power which can be delivered as electricity depends both upon the efficiency of the extraction device, and upon losses due to varying wave direction.

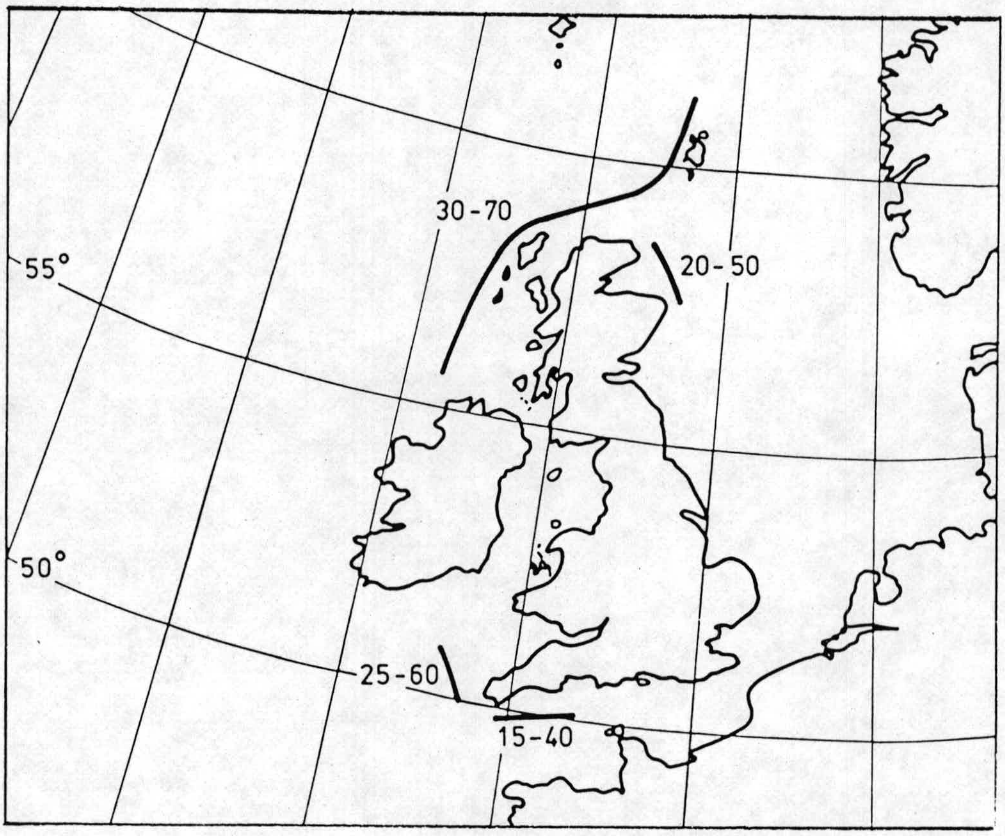


Fig. 1.1

From the designers point of view the most interesting waves are progressive i.e. they carry energy from one location to another.
In a travelling wave in deep water, each particle moves in a nearly circular orbit. At the surface the diameters of these circles are the same as the wave height, and the diameter falls off exponentially with increased depth.

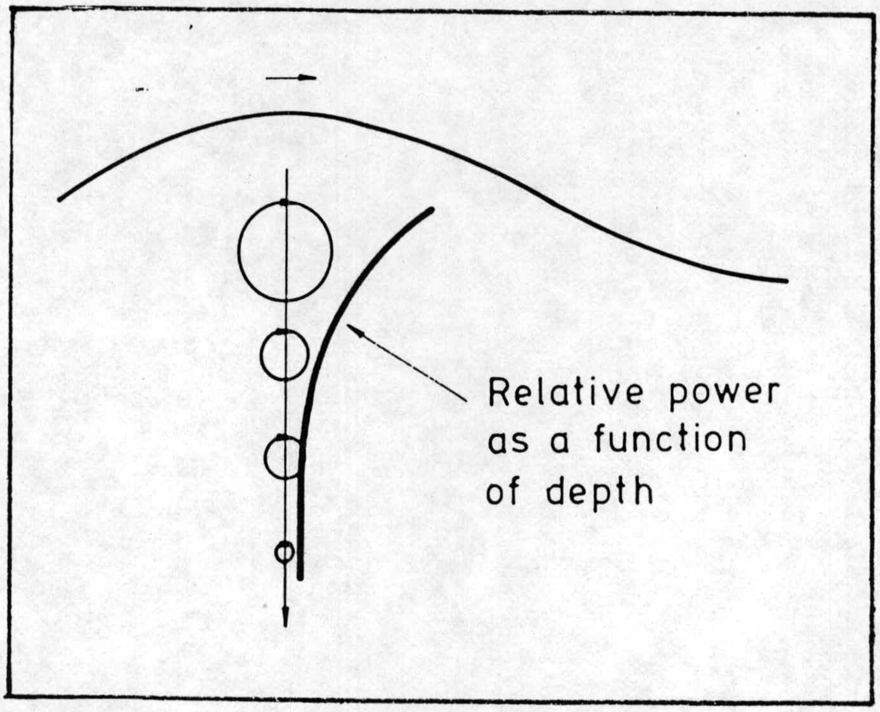


Fig. 1.2

The amount of power in a wave train can be estimated by calculating the change of potential energy as the water in a wave crest, above sea level, falls into the trough in front of the wave. Kinetic energy is also present because of the wave motion, and in deep water the K.E. is equal to the P.E. Progressive waves transport energy across the sea and it is valid to say that the rate of transport of energy across some line is power. Power density can be specified in kW/m of frontage.

The Institute of Oceanographic Sciences publish data which is invaluable to anyone interested in waves.

The science of wave climatology was needed for wartime landings and then came increasing demand for information for the building of lighthouses, pipelines, breakwaters, harbours and in more recent years, for oil platforms, hovercraft and hydrofoil services.

The information has been built up with the aid of three main types of wave recorder, on the seabed, on the surface and on ships.

One of the first recording devices was the spark plug recorder. This consisted of a series of spark plugs each having a horizontal electrode, stationed in a vertical line with the plugs a few inches apart. As the waves rise and fall the plugs under water are shorted and a record can easily be collected and translated.

This device was ingenious but not as sensitive as other devices, some of which are designed to register differences as small as 0.25mm.

One such development is an underwater device with a pressure sensor.

This has the advantage that it is less likely to be damaged by shipping, however it can only be used in fairly shallow water, around 12m, as waves do not penetrate too far into the sea.

The device is a metal box which sits on the seabed. As a wave crosses the site the depth , and therefore the pressure increases and the box records the extra height. The information can either be recorded on a graph, or a cassette, in the box itself, or back at the shore. A more sophisticated device, which can be used in deeper water, is the Shipbourne Wave Recorder invented in 1951 by an I.O.S. scientist, Mr. M.J. Tucker.

A pressure sensor is mounted inside a stationary ship such as a weather or light ship, just below the waterline. A hole is bored in the side and as the water level outside rises and falls the pressure sensor records the changes. This has to be coupled with an accelerometer which registers the movement of the ship itself. The two readings are then added together and the information is printed out as a graph showing a picture of the waves at the site.

Recently another device has been increasing in prominence, a Dutch invention the Waverider Buoy.

This is a bright orange and yellow sphere about 80 cm in diameter, moored to the sea bed by a "piece of elastic". Waverider buoys use electronic integrators to convert buoy acceleration into displacement, so that a waveheight/time record is obtained. A 27 M Hz transmitter sends data back to the shore, about 20 minutes of data being recorded every few hours.

The limited range of the transmitter and the large amount of interference, limit the location of buoys to about 30 km offshore.

The data provided by these means enables the forecasting of the height of waves by a means called "hindcasting" developed by Professor J. Darbyshire. He uses the relationship between the strength of the wind, the distance over which it has blown and the time taken, to calculate the wave heights.

Much of the data used in the early stages of the wave energy programme was collected by O.W.S. India situated at 59° N latitude, 19° W longtitude, but as can be seen from the map there are many other collectors in operation.

Plans are being made for work on the installation of new buoys in locations determined by the specific needs of the programme, as well as investigations of the usefulness of satellite radar data.

Results from the data so far, suggest that the best location for wave energy converters are off the Hebrides, where power levels of 30 - 60 kW/m are available, plus several hundred kilometres of sea room.

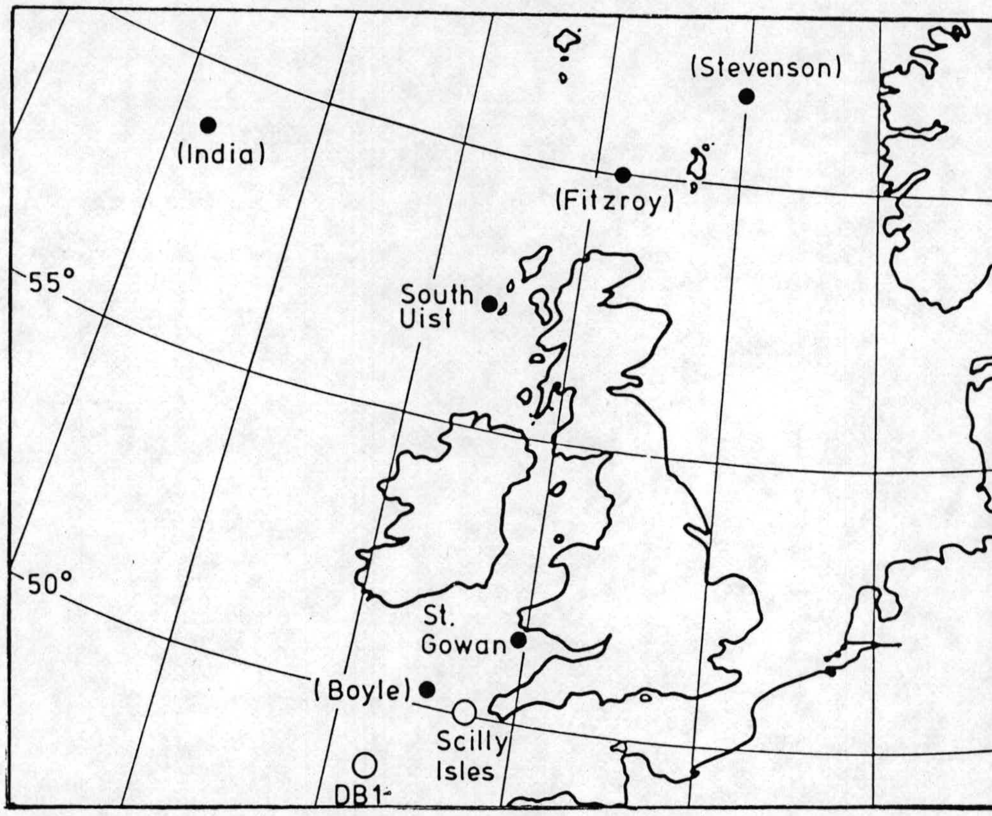

(Stevenson)
(India)
(Fitzroy)
55°
South Uist
50°
St. Gowan
(Boyle)
Scilly Isles
DB1

Fig. 1.3

2. In The Shadow Of Westminster

Wave power is innovatory as far as serious investigation is concerned but it is not a new concept.
Probably the first ever patent for a wave energy device was filed on July 12th, 1799 by a father and son named Girard, in Paris. Their idea was to build a gigantic lever with its fulcrum on the shore and with a "body" floating on the sea. As the body moved up and down with the motion of the sea, the lever would also move up and down and could be used to drive pumps, or bucket wheels etc. The patent was discovered and translated by Alan E. Hidden, an engineer at Queen's University, Belfast.

It is estimated that between 1856 and 1973 over 340 British patents for wave powered generators were granted. (See Appendix I).

If the numbers of patents submitted from 1860 to the present day were plotted on a graph then it would show an approximate s-curve (See Fig.1.) Only two or three patents were being granted each year between 1860 and 1890 but this rose to around six per year between 1900 and 1930. After 1930 the rate slowed down, settling to about one a year between 1935 and 1970. The annual number of patents submitted in recent times has increased but the rate is unlikely to reach the numbers seen in the 1900 - 1930 period.

Some designs even reached the building and testing stage. The first of these being in 1910. This was, once again, a French idea, built at Royan, near Bordeaux. It consisted of a vertical bore hole in a cliff, the oscillations in water level being used to drive an air turbine. It provided 1 kW of electricity and was used to provide the entire power and lighting for a house.
However most of the designs proved to be of low efficiency as can be seen in Table I. More recently though successful operation at low power levels, for buoy and lighthouse use, has been achieved.

Pioneering work by Masuda, of Japan, has resulted in the installation of more than 300 generators in the 70 - 120 watt region of output for powering light buoys and lighthouses in Japanese waters. These devices are based on the idea of an oscillating water column transfering energy from the waves to air to drive an air turbine.
A study of large wavepower generators began in 1974 at the Japanese Marine Science and Technology Centre, based on Masuda's ideas. After two years of basic study and work with small models in water tanks, a large scale device, Kaimei was developed, 1976. Its maximum output was expected to be, (in 3m waves) about 2 MW, but so far in preliminary trials, power levels of only 0.6 MW have been achieved. These tests took place in the Sea of

Japan in 1978 and are being followed through by tests, through the International Energy Agency, in which the U.K. is taking part.

In March 1976, a working party on Ocean Energy Systems of the International Energy Agency was formed, to bring together these countries, from the O.E.C.D. who had a common interest in developing wave energy. In the May of 1978 the formal signing of an agreement for a collaborative programme on wave energy, took place.

The U.K. together with Canada and the U.S.A. accepted an offer to enter into joint programme (with the Japanese) of further work on the Kaimei. The project was joined by Eire in 1979.

Government interest, in the U.K. began formally in 1974 with the publication of a report entitled 'Energy Conservation' by the Central Policy Review Staff.

The report recommended that the first stage of a full technical and economic appraisal of harnessing wave energy for electricity generation should be put in hand. Acting on this recommendation the Department of Energy commissioned a study of the potential of wave power, which was carried out by the National Engineering Laboratory and was submitted in March 1975.

Based on the results of this report in April 1976, the Government announced the start of a two year study costing about £1 M, the aim being to "establish the feasibility of the large scale extraction of power from sea waves and to generate information which would enable the cost of further development to be investigated".

The Government was involved in wave power before 1974 as the figures below show.

Funding by Government on Wave Power R & D

1973 - 74	£10,000
1974 - 75	85,000
1975 - 76	117,000

The new Department of Energy was set up in 1973, in the haste of setting up the Department no research budget had been allowed for and some of the funds in those first years came from the Department of Industry.

Below is a table showing the organisation of the Department of Energy's R & D programme on wave energy.

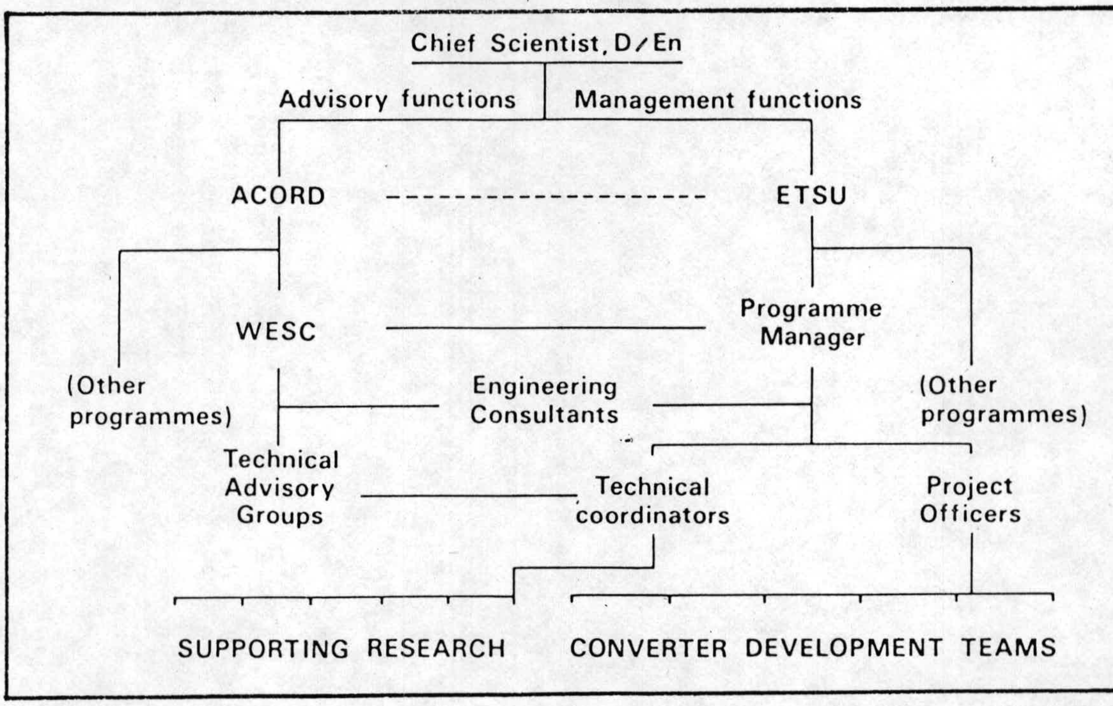


Fig. 2.1

The organisation of the Department of Energy, shown above, is managed by the Energy Technology Support Unit (ETSU).

The Energy Technology Support Unit was formed in April 1974. The Unit was originally set up to supplement the resources of the Department of Energy in examining the technological options available to the U.K.

ETSU's current responsibilities are more specific. They provide direct support to the Chief Scientist on:

- the scope for development of new energy sources
- the scope for research and development leading to energy conservation in the medium and long term.

to carry out such other work relating to energy research and development as the Chief Scientist may from time to time require.

The programme for the Unit is determined by a steering committee of which the chief scientist is chairman.

As far as wave energy is concerned this committee is the Wave Energy Steering Committee (WESC).

The WESC was set up after the publication of NEL's report in 1975. The Central Electricity Generating Board (CEGB) also put to the Advisory Council on Research and Development for Fuel and Power (ACORD) in May 1975 a review paper describing their work in this area.

ACORD discussed the papers by NEL and CEGB in June 1975 and recommended the setting up of a Steering Committee to prepare a national programme on wave energy.

This recommendation was based on the following considerations

1. The potential size of the resource large.

11. There is a good seasonal match between the pattern of electricity demand and the incidence of wave energy.

111. The wave energy conversion systems proposed were modula, therefore there would be no need for a very large single investment.

IV. The technology involved could borrow much from marine engineering and experience in offshore exploration.

V. The system should be environmentally acceptable since they would be well offshore and of low freeboard.

Consequently the first meeting of the WESC was held on the 1st August 1975. The steering committee draws members from many sources re ETSU, CEGB, Science Research Council, Ministry of Defence as well as from the Departments of Energy and Industry.

The terms of reference of the committee are

(1) To draw up and agree a national programme of work for the study of wave energy;

(11) To advise on the implementation and management of that programme;

(111) To advise on the technical briefing of U.K. delegates to international meetings on wave energy;

(1V) To report to the Chief Scientist, Department of Energy, on matters relating to wave energy.

The work of the committee and of converter development teams has been supported in general research areas through a series of Technical Advisory Groups (TAGS) details of which are given in Appendix 2.

When the study was announced in 1976 the information available was insufficient to allow a firm choice of a single engineering concept to be made from the wide variety offered. Consequently four basic designs were chosen for investigation.

The four designs which formed the major part of the two year programme were

(1) HRS Rectifier

(2) Oscillating Vanes (ducks)

(3) Wave Contouring Rafts

(4) Oscillating Water Column

It is to the development of these that we will now turn.

3. The Early Contenders

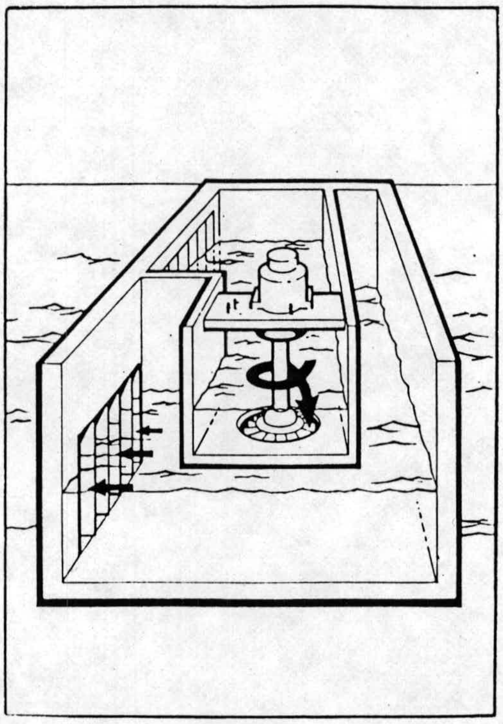
In 1976 the four converters chosen for further investigation were:-

1. HRS Rectifier
2. Salter Duck
3. Cockerell Raft
4. NEL OWC

I am going to look firstly at the HRS Rectifier, mainly because it evolved from a scheme in Mauritius more than 20 years ago.

The Hydraulics Research Station was first involved in wave power in the 1960's when they were invited by Walton Bott, of the electricity authority Mauritius, to look at a scheme put to them by consulting engineers Alexander Gibb and Partners.

Mauritius has a coral reef and behind the reef is a lagoon. The proposal was that the coral reef should be modified in some way to make it into a ramp. Waves breaking on this ramp would rush up to the top and tip over into the lagoon, thus raising its level. A low head turbine placed between the lagoon and the sea would generate power as the water ran back through the turbine. The Hydraulics Research Station was invited to make some prediction of how much power would be obtained by waves of different sizes, types and lengths, and how to optimize the height of the crests. They did the prediction but the scheme did not go ahead due to problems in constructing the ramp, on top of which came the drop in oil prices in 1966. But the plan remained and after significant design changes reared its head again at HRS in 1975.



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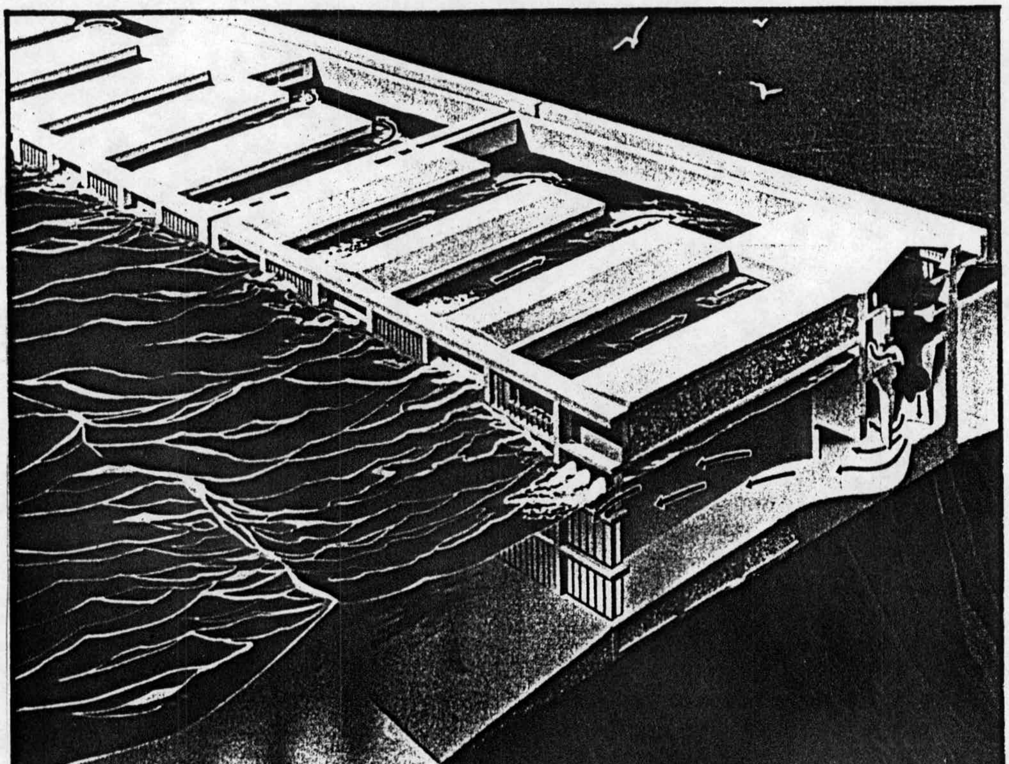

Fig. 3.1

The HRS Rectifier works on principles similar to those of tidal power. Wave peaks drive sea water through non-return flaps into a high level reservoir. From there it is fed through low head turbines into a low-level reservoir and then discharged to the sea via non-return flaps during wave troughs.

It is this intermediate reservoir which makes it different from the original Mauritius scheme. The rectifier received a Department of Energy grant in November 1976 but work was discontinued in 1979 due to high structural costs and its low average output.

SALTER DUCK

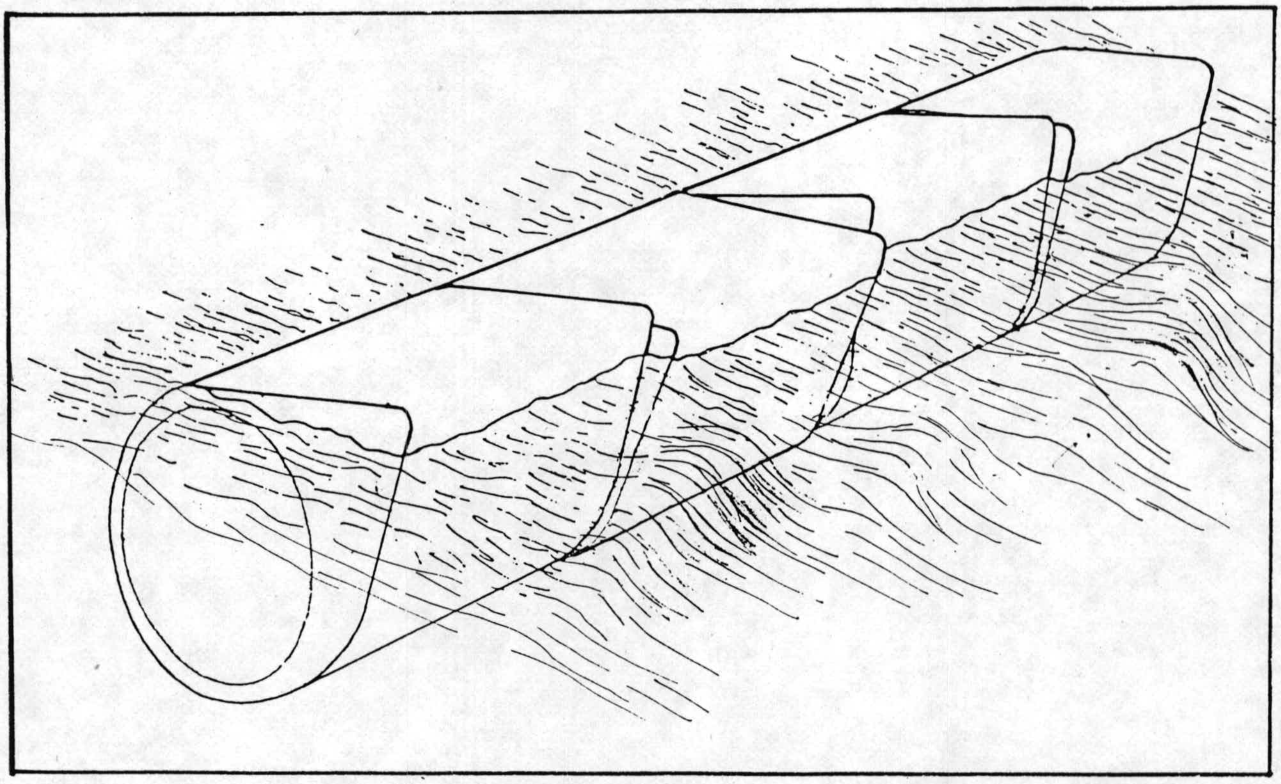

Fig. 3.2

The "Duck" as it is called is the invention of Mr. S.H. Salter of Edinburgh University.

Of all the wave devices mentioned, it is probably the most famous.

Mr. Salter began work in 1973 to develop a source of energy which would be clean, safe, permanent and which would work in winter in this country, and decided that waves were the most suitable base. He built various models and the instruments to test their performance and, through a gradual evolution, came up with the "duck".

His first extraction device was something like a lavatory ball cock bobbing up and down but that only captured about 15% of the available energy. He found that if this were tipped so that the hinge was below the surface the extraction was much higher, about 60%. A vertical flap was then tried. Its movements displaced water behind it, making a new wave with about 25% of the energy and thus making it harder to move and this resulted in a figure of 40%. The next model was shaped something like the British standards kite mark. This did not displace water and got out about 70% of the available energy. Then there was the tadpole which was no more efficient and it was more difficult to make.

Eventually, with the aid of a computer, the "pregnant duck" shape was evolved which can get 90% out, at its best.

The duck acts as an oscillating vane, nodding up and down under wave action through 60° arc on a spine at its rear, parallel with the sea fronts.

Originally the power take off from the duck was to be by radial piston hydraulic pumps, however Mr. Salter has now devised a unique way of power extraction using gyroscopes.

Pairs of gyros would be sealed inside the ducks beak spinning in opposite directions. Under wave action the gyro assembly would rotate through $\pm 90^{\circ}$ in a horizontal plane. This precessive force is harnessed through ring cams attached to the gyro gimbals. A circle of hydraulic pumps which bear on the rings are activated by the cams dragging over them as the gyro precesses.

The gyros swing through 180° and back typically once every 10 seconds.

When Stephen Salter started his work back in 1973, it was privately financed for quite some time due to the lack of a research budget in the new Department of Energy. However in 1974 it was arranged that he should have a grant from the Department of Industry. This amounted to some £68,000. He was granted a further £180,000 in 1976 as one of the four devices studied at the start of the U.K. wave energy programme. He used Lanchester Polytechnic for computer simulation and in 1/10th scale Loch Ness trials in 1977/78.

The Loch Ness trials used a 25 ft. assembly of 20 ducks on a 50 metre long spine and the test lasted 3 months.

Tests at 1/150th the scale have been conducted at Edinburgh University in wave (testing) tank, 30m by 12m which was commissioned by the Department of Energy in 1977.

He was granted another £400,000 by the Department of Energy in 1978, when contractors John Laing and consultants SCOPA (Scottish Offshore Partnership) entered for extensive full-scale design studies.

The duck has been called the "fast reactor of the wave power field" suggesting that it is elegant but complex. It seems to be this complexity and fears about reliability which led to the withdrawal of Government funding in mid 1980, but in October a £232,000 grant to Edinburgh (including money for tank maintenance) was confirmed, for generic studies on spines, gyroscopes and oil hydraulics, in which the duck will continue to be used.

The Ducks are claimed to be amongst the cheapest of the devices, and also one of the smallest. In a full scale device, ducks 26m wide, with a captive width of 30 metres have been suggested. For a 2GW station some 1,000 ducks would be needed, they would probably be moored in water 100m deep and the string of ducks would stretch for some 30 km.

Cockerell Raft

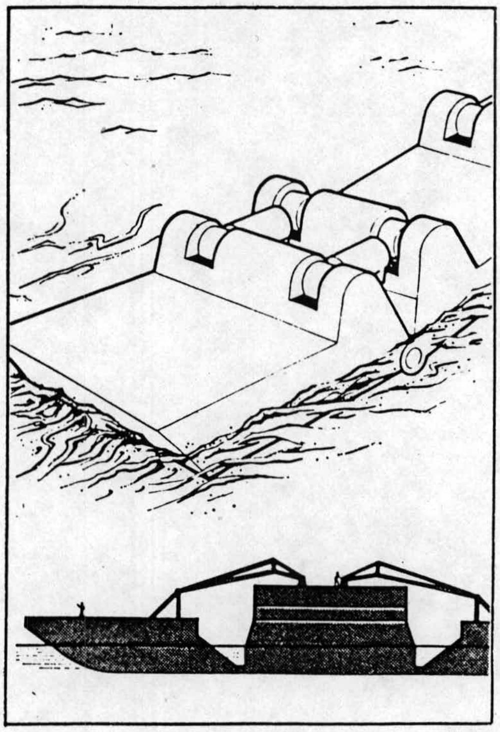

Fig. 3.3

This concept was originally evolved in 1972 by Sir Christopher Cockerell, but at the time there was no official interest.

In 1973 he joined forces with two friends EWH Gifford and MV Woolley of EWH Gifford and Partners, Civil Engineers, and jointly formed the company Wavepower Limited.

With the oil price rises came increased interest in the project and although he had no government funding he managed to get the British Hovercraft Corporation, at their own cost, to build a simple tank model of his device, The Central Electricity Generating Board constructed a more sophisticated model of his device (1974) and obtained performance characteristics similar to those of Salters ducks (about 80% efficiency) in tests in the Hythe test tanks.

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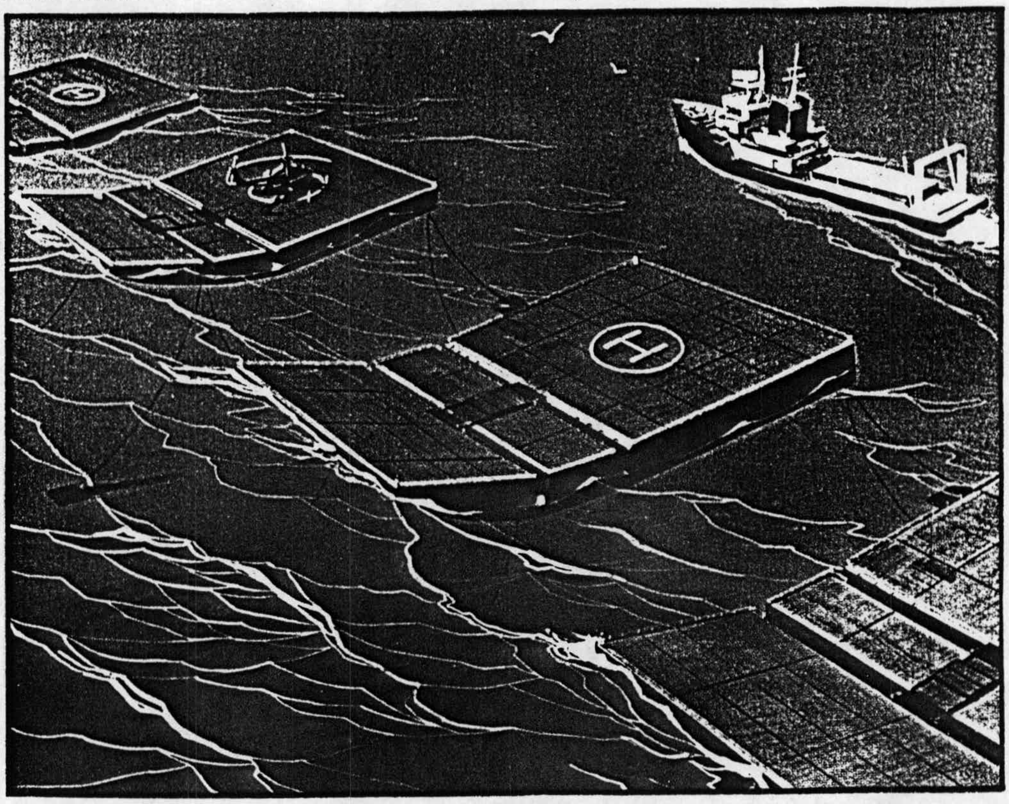

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In May 1975 Wavepower Ltd approached the Department of Energy for financial support, which it received in 1976.

In 1978 1/10th scale models were tested in the Solent using a three rafts line up. Funding stopped in 1979 mainly because the devices were expensive, the structures needed would be very large (about 100m long and 50m wide) and the hydraulic system which was to be used was found to be vunerable to corrosion and erosion.

For a 2 GW station more than 900 rafts (each costing £4 million) would have been needed.

4. NEL OWC

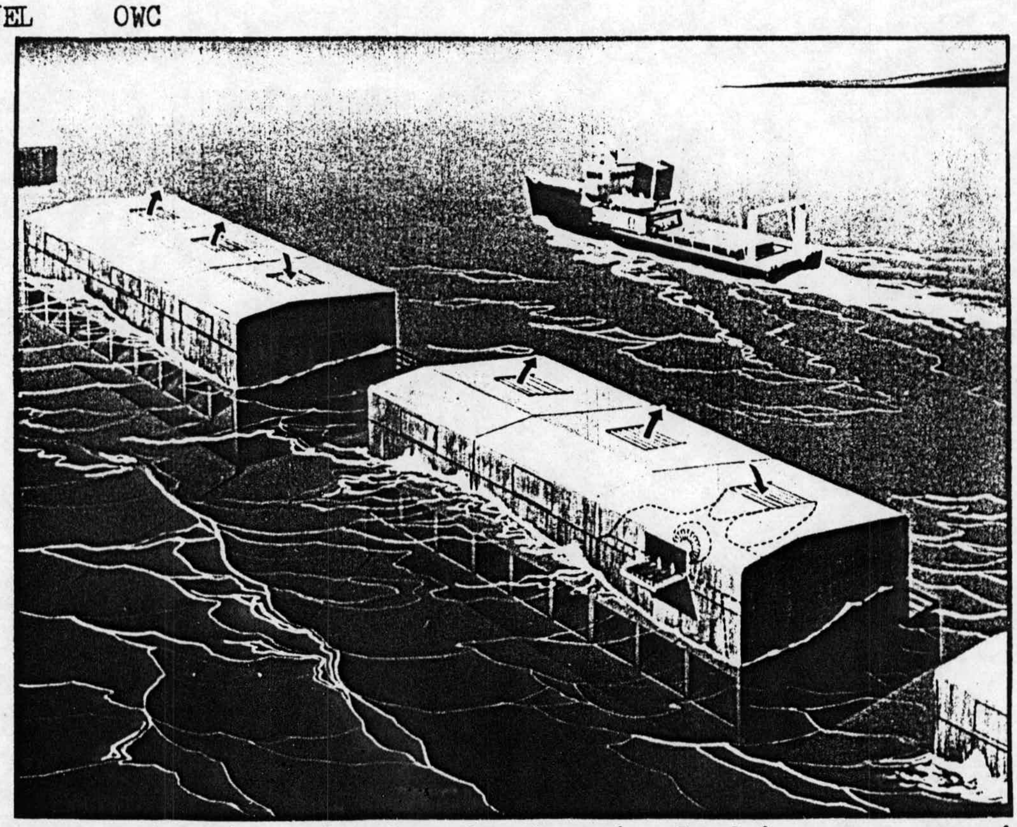

Fig. 3.4

The National Engineering Laboratory has been involved in wave power since 1974 when they undertook a feasibility study on behalf of the Department of Energy. The study described the Masuda (Chap. 2) device as "the most promising scheme" on the grounds that it had no large moving parts, high

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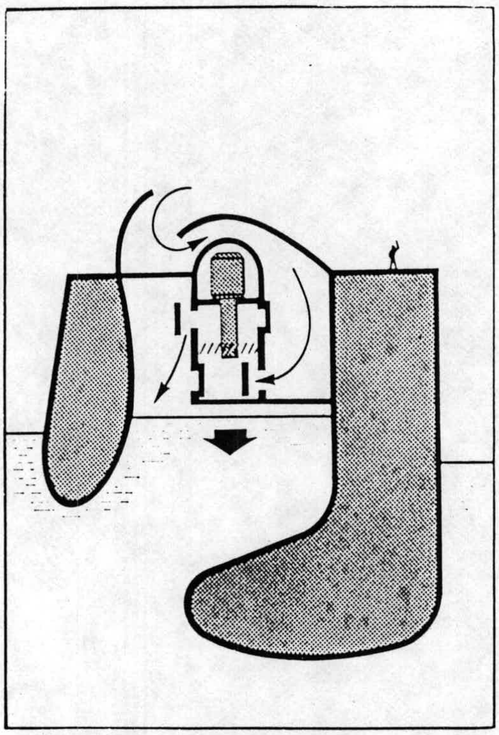
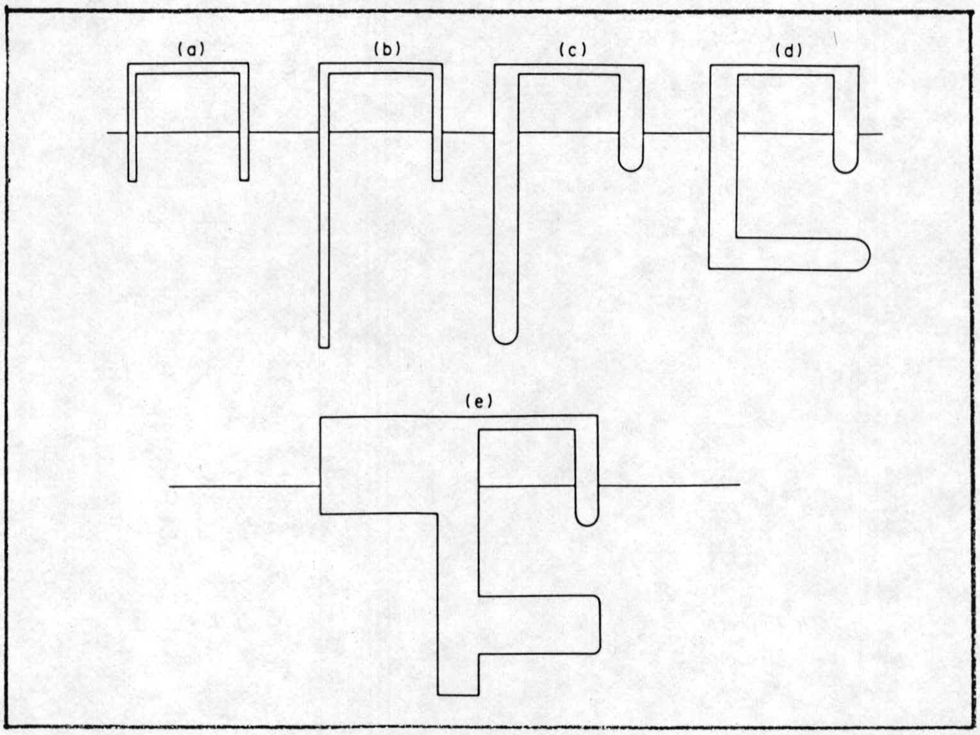


Fig. 3.4

The National Engineering Laboratory has been involved in wave power since 1974 when they undertook a feasibility study on behalf of the Department of Energy. The study described the Masuda (Chap. 2) device as "the most promising scheme" on the grounds that it had no large moving parts, high efficiency for wave to air energy conversion, a valved air turbine generator which had already been demonstrated as effective and reliable in small units, fabrication of the floating ring buoys could be undertaken using existing shipbuilding and construction technology and that the system has a higher credibility rating than most others.

NEL decided to participate in the development of wave energy devices and selected the oscillating water column concept as being most appropriate to their expertise, already having experience in offshore activities as well as their special facilities in turbo-machinery. They submitted a proposal to the Department of Energy to examine the OWC and in 1976 were granted the funds to do so.

The initial investigations involved examining the simple inverted cylinder oscillating water column concept, the principle being that the rise and fall of waves in the inverted culinder forces air back and forth through an orifice at the top. The reciprocating air flow produced could be rectified by one way louvre valves and passed through an air turbine.



With various changes in the shape NEL managed to raise the efficiency of the device from 30% to 70%, and by using a base plate at right angles to the longer rear wall raised it to 90%.

At this stage it was necessary to call upon the services of a consulting engineering organisation experienced in civil and offshore work and Roxbergh Partners were selected. By 1978 two full scale designs had been produced for a 100 MW station.

One design of steel construction to be built by conventional shipyard techniques and the second of reinforced concrete.

These designs were both floating structures, and after cost analysis proved to be three to five times more expensive than acceptable.
Oscillating water Columns fixed to the seabed had been considered early in the programme but were initially discorded because it seemed that they would be inefficient in shallow water. However examination of the costs suggested that they would be cheaper in the long run than floating devices as about a third of their costs related to moorings.

An outline floating version in 1979 was costed at double the breakwater version.

In a full scale lay-out the wave chambers would each measure 15m wide and would be grouped in fours into a 60m device.
The breakwater device would stand on the sea bed in 15 - 20 metres of water.
NEL estimated that a 29 W station would require some 50 km of breakwater, plus 10 km of navigation gaps.

Since the Government announced its wave energy programme a steady stream of new proposals has been received by ETSU which acts as the primary point of contact for the inventors. Over 40 new ideas were considered in 1977.

The Wave Energy Steering Committee set up a Technical Advisory Group (TAG 1. see Appendix 2) to assess and advise upon new concepts, and initiate work on those which show promise.
The important criteria in assessing those new ideas are cost effectiveness and engineering feasibility.

Many ideas are immediately abandoned but some have gone on for further study and it is to these that we now turn.

4. The New Recruits

Since the recent finding decisions of 1980/81 funds from the Department of Energy, though not reduced are to be concentrated on four devices. These are the Lancaster Flexible Bag; Bristol Oscillating Cylinder and the Oscillating Water Columns of NEL and Vickers.

Vickers has been working on wave energy for four years, using its own money and Department of Energy grants, the latest of which is £125,000 announced in September 1980.

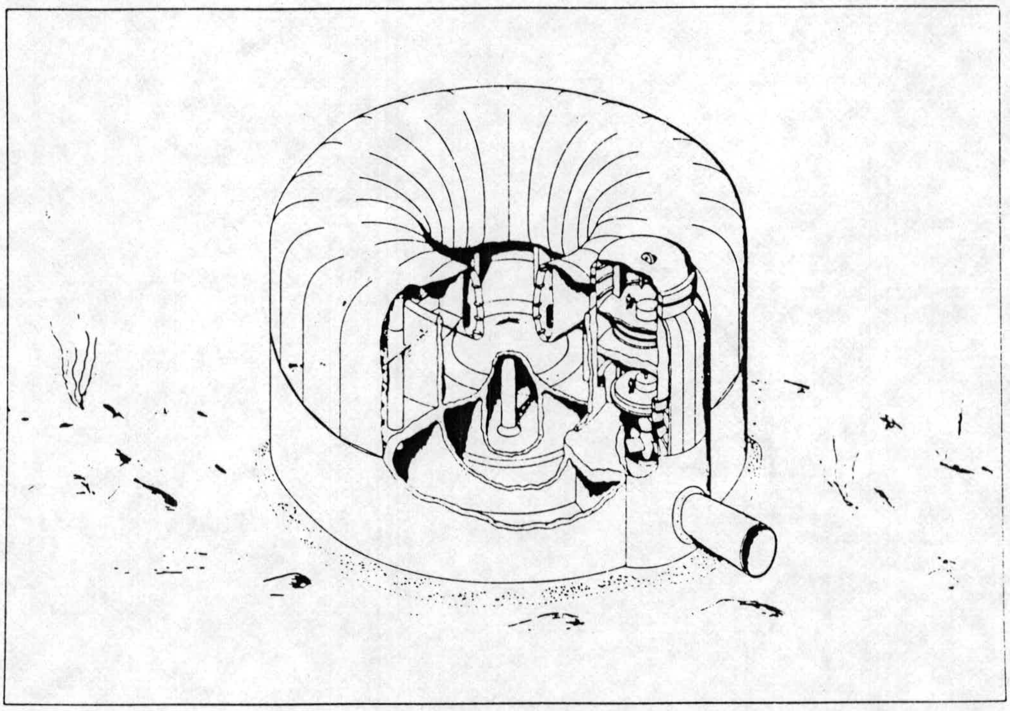


Fig. 4.1

Early work on a single column 'submerged resonant duct' resulted in the two groups of OWC device currently being studied, the Twin OWC and the submerged wave chamber.

The Twin OWC uses the pressure changes due to changes in the depth of water as a wave passes over the submerged device. This pressure change induces a resonant and amplified oscillation in a water column open to an air chamber enclosed within the structure.

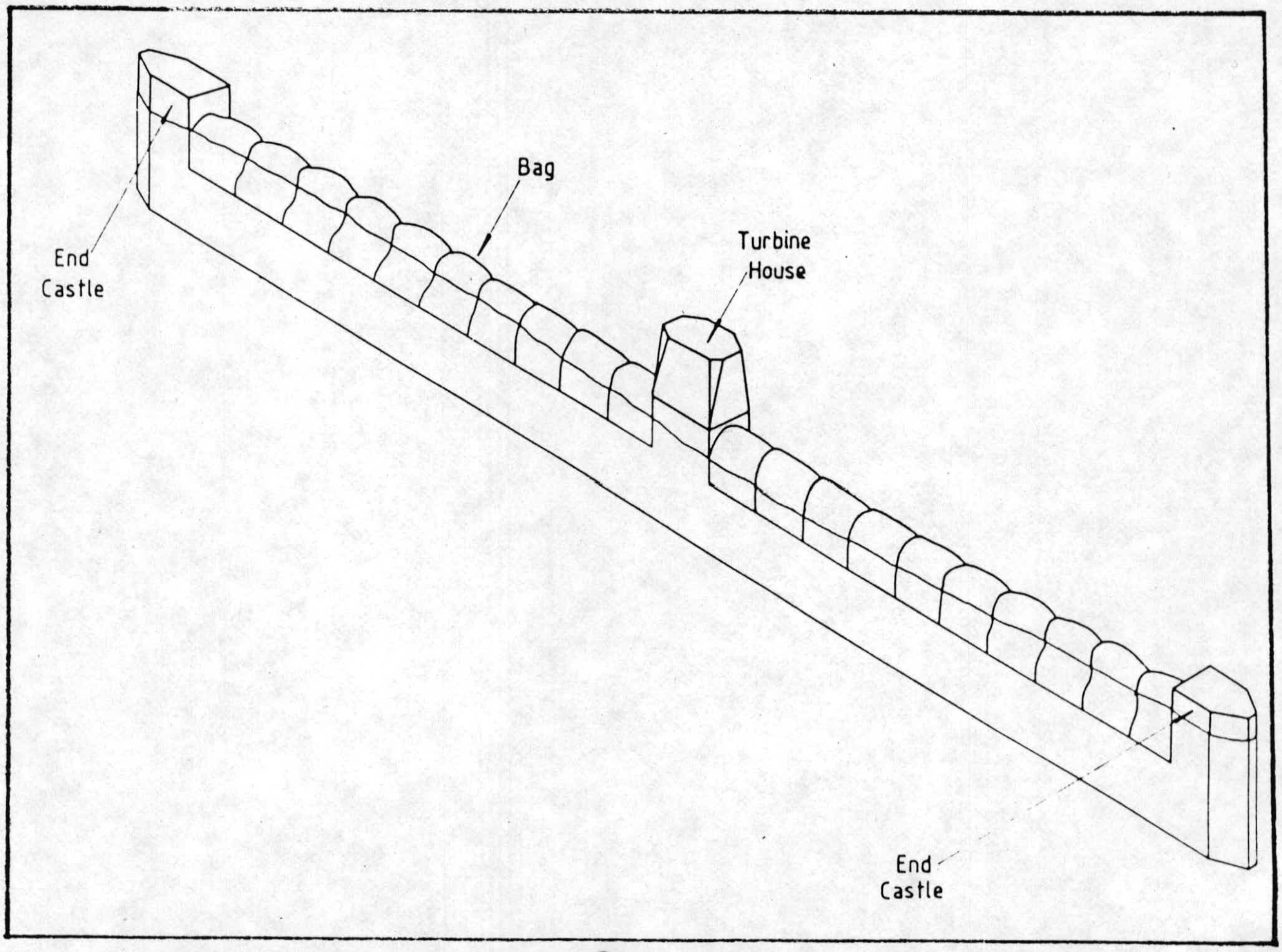
The Twin OWC does not need the compression of a large volume of air which the early 'duct' did. Instead by linking the main column to a second column alongside it fools the device into thinking that it contains a far greater air volume than it really does. Power is extracted by self-rectifying turbines placed in the alternating air flow caused by the net difference in oscillations of the two side by side columns. Differential movement of each column is ensured by placing the outer inlets at widely differing levels on the structure and also displacing them laterally. The main inlet faces upward on top of the structure, where it senses the full effect of the wave pressure variations. The second inlet looks out horizontally near the base of the device, at a depth where pressure fluctuations have decayed significantly.

Vickers feel that the Twin OWC would be best employed as an inshore bottom standing device, built of concrete. Likely dimensions being 17m high, 22m wide and 32m long, the structure being about 5m below the water surface.
For a 2 GW station it is estimated that 2,000 devices would be needed.
The submerged wave chamber uses the action of waves passing over the long attenuating device submerged in deep water, end-on to the crests to excite a secondary wave in the free surface of a chamber running along the inside of the structure.
Power can be extracted either by dividing the chamber into cells and using the alternating air flow between them, or to obtain a rectified air flow by trapping pockets of air between successive wave crests, so pumping them to the inshore end of the device where the air flow can be fed through a turbine and then returned to the other end once again. Of the two methods the first is the most efficient.

The device would be built of steel. It would be likely to have a 10m square cross section and be 12m long, situated in 60m of water, 5m below the surface.

Once again for a 2 GW station 2,000 of these devices would be needed.

Lancaster Flexible Bag Fig. 4.2



This concept was invented by Professor French of Lancaster University who has worked on the idea since 1977. Early work was funded by the Science Research Council. In 1979 Lancaster teamed up with Wavepower of Southampton and in June of that year they received a £175,000 grant from the Department of Energy for continuing development.

The Lancaster device has flexible rubber air bags running along either side of a long narrow, semi-submerged, rigid hull lying end on to incoming seas. The bags are divided by flexible membranes and the compartments so formed are alternatively compressed as a wave crest passes down the device, then released and reinflated in the wave troughs. This bellows like action feeds pulses of high pressure air through non-return valves into a duct and on to a central turbine in a conning tower. The low pressure air coming from the turbines goes back to reinflate the bags so the air system is completely closed.

The two most prominent features of the bag have both changed shape since 1978. In 1979 the long bag was separated into separate sections by rubberised fabric diaphragms, to try to get over the problem of fatigue inducing kinks (where a lateral wave caused the bag to become distorted).

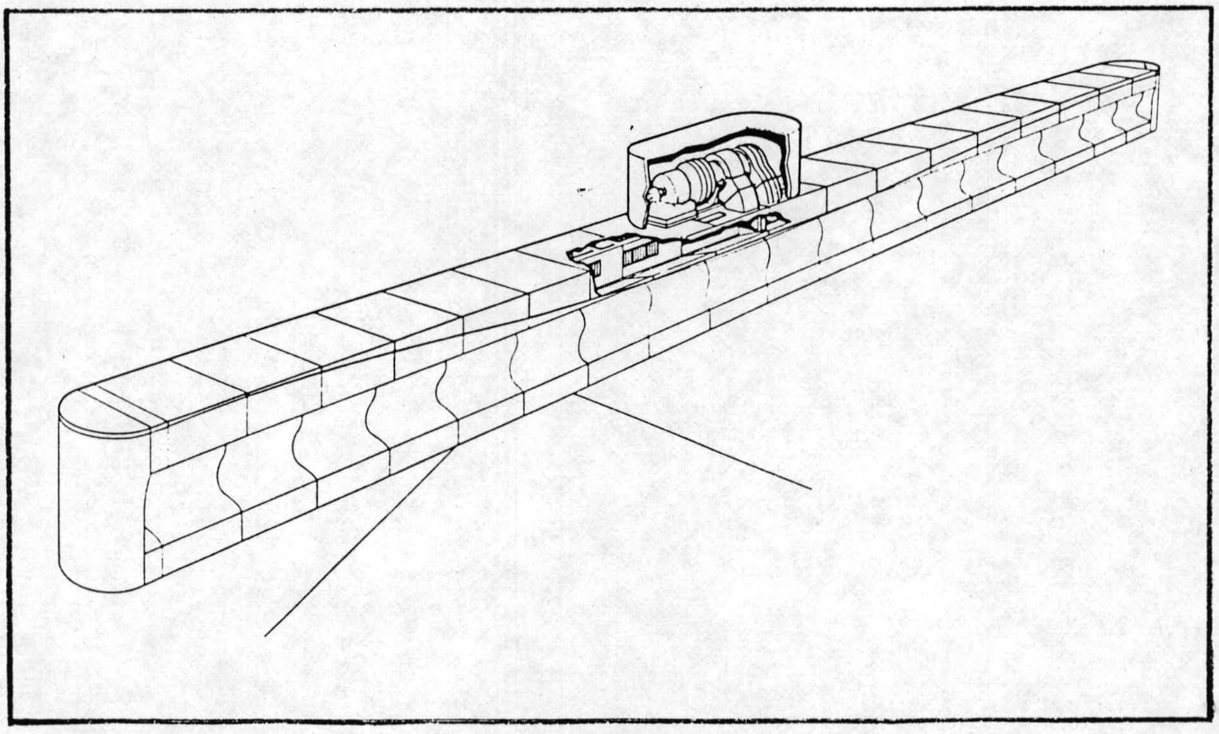


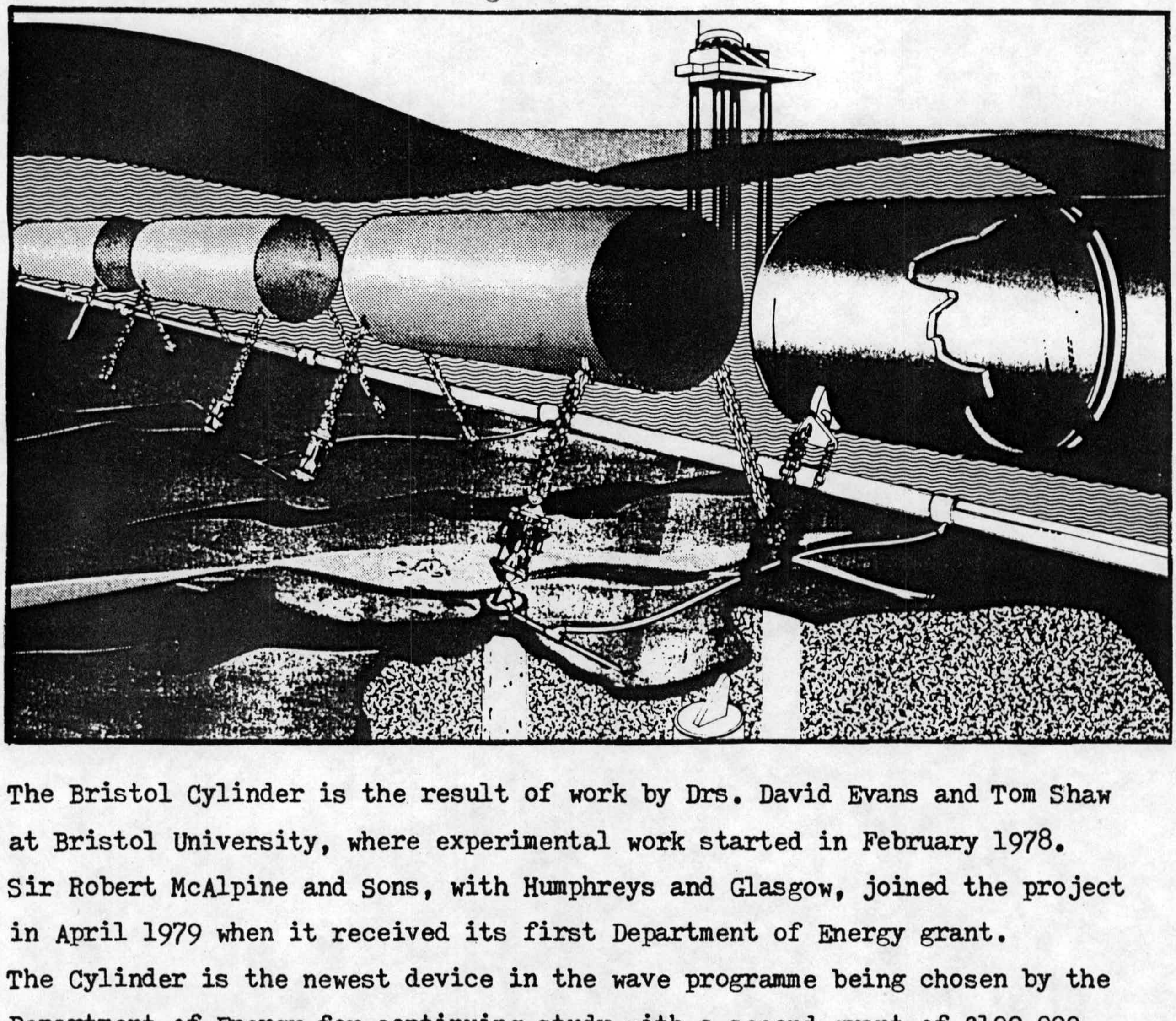
Fig. 4.3

At the same time the structure size was increased to cater for the vertical bending mo ement likely to be imposed on a device with a 200m long spine.

The 1981 Hull design is still taking place but figure   is indicative of current thinking.

In the early stages of the U.K. wave energy programme there was a shortage of suitable tank testing facilities to cover the range of conditions met by wave energy devices. This led to the development of tanks specifically designed for the purpose, able to model multi-directional random seas with realistic frequency and directional spectra between 1/100th and 1/50th scale. The first of these tanks was the one at Edinburgh, the second was commissioned at Wavepower Limited premises in Cadnam during 1980 and a lot of the recent development of the flexible bag has been due to this.

Bristol Oscillating Cylinder Fig. 4.4



The Bristol Cylinder is the result of work by Drs. David Evans and Tom Shaw at Bristol University, where experimental work started in February 1978. Sir Robert McAlpine and Sons, with Humphreys and Glasgow, joined the project in April 1979 when it received its first Department of Energy grant.
The Cylinder is the newest device in the wave programme being chosen by the Department of Energy for continuing study with a second grant of £109,000 in September, 1980.
The device is a submerged buoyant cylinder anchored parallel to the wave crests. The orbital motion of the waves pressure field around the cylinder as it passes overhead causes the cylinder to orbit around its static

position, so varying the tension in its moorings. This motion is transferred via the moorings to a power take off (picking up the movement as an almost linear reciprocating motion) at the sea bed connection between each mooring and its anchor. High pressure water or direct mechanical generation could be used.

Experimental work at 1/120th the scale have been done both in a narrow wave flume at the Civil Engineering Department of Bristol University and in the Department of Energy's wide tank at Cadnam.

On present evidence in a full scale layout the likely cylinder dimension would be 50m long and 12m diameter and situated about 6 - 8m below water surface (deeper than this the wave energy begins to decay).

Cylinders are rated at about 2.5 MW output therefore a 2 GW station would require some 800 cylinders in 40m of water, with a gap of 25 - 50m between them.

The Clam

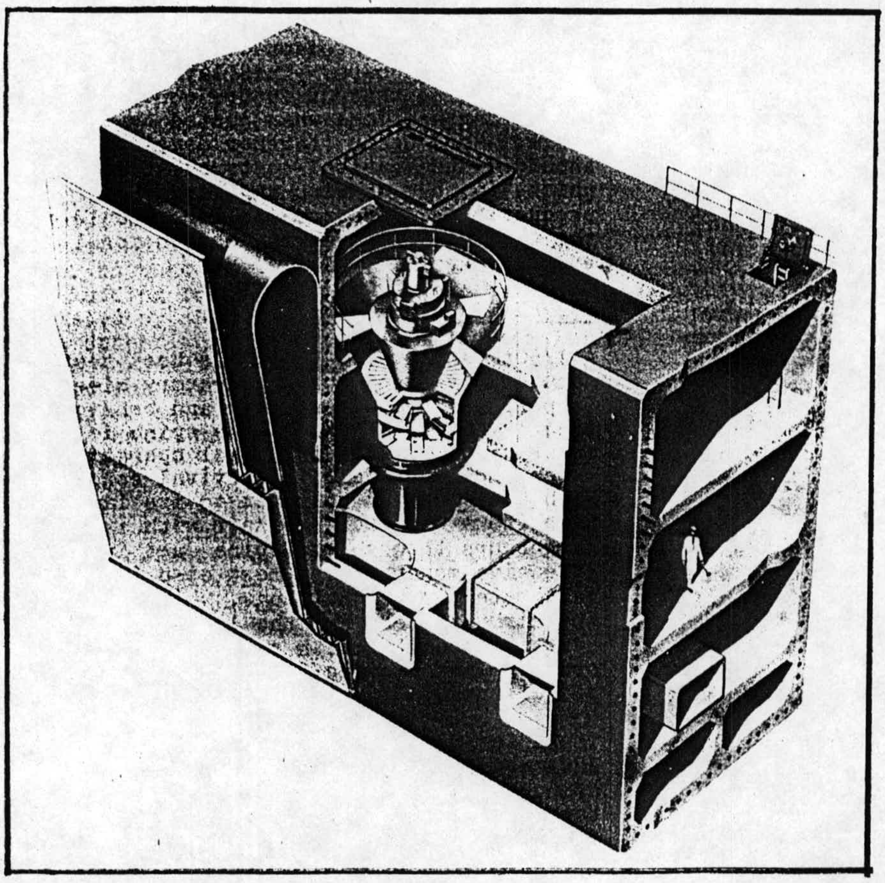


Fig. 4.5

Although this device was evolved earlier than some of the others mentioned, I have left it until last as it does not belong to the official government wave energy programme.

The Clam was the idea of Dr. Norman Bellamy of Lanchester Polytechnic, Coventry, who is a member of Sea Energy Associates (a consortium of Ready Mixed Concrete, Cawoods and inventors). SEA is the group which is funding research into the Clam at Lanchester.

SEA - Lanchester have been involved in wave energy since 1976, including the 1/10th scale trials of the Salter Duck in Loch Ness. The Clam concept evolved in 1979 and although no Department of Energy funds have been granted for the device, Lanchester received £187,000 in September 1980 for studies into spines and moorings.

The Clam can be classified as a spine based pneumatic terminator. It consists of large air bags sandwiched between a main structural floating spine and an outer hinged flap. These are face on to the prevailing sea. Waves push the flaps in, forcing air out of the bags and through self rectifying turbines. The air is in a closed circuit and when the flaps move out in a wave trough the air returns to the bags.

Further development on the Clam aims to eliminate the expensive steel flap and mechanical hinges used at present in favour of a totally soft fronted Clam.

Spine models have already been tested in Draycote reservoir and in tests in February 1981 in Loch Ness at 1/10th scale model of a 300m long rectangular Clam beam, without bags to assess bending movements and mooring forces. In a full scale layout ten Clams would probably be used, linked together to form a 300m long spine rated at 10 MW, with a 4 MW mean output. A station rated at 2 GW would require 80 km of coastline.

If wave energy is ever to contribute a significant amount to the nations energy demand then there are many associated problems which must be solved first. These problems include errosion, corrosion, stress, marine fouling, moorings and those associated with transmission. At least the first three of these depend upon the choice of the main structural material used in the device. Valuable experience on the use of concrete structures already exists and this suggests that these structures can survive for long periods in the marine environment e.g. the Tongue Sands Fort, 13 km off Margate.

Considered as a structural material concrete has a big advanatge in that it can be made in pre-cast units, and consistent quality can be maintained in the process. By using reinforcement or prestressing, concretes negligible tensile strength can be overcome and its compressive strength (though not as high as that of steel) is high enough to result in very economical compression sections.

In 1976 the Department of Energy, in collabaration with about 20 companies, initiated a programme 'Concrete in the Oceans' to deal with the problems associated with concrete oil production platforms. It is hoped that this work may provide data relevant to the wave energy programme. Steel is a possible alternative to concrete as the main structural material. Even if it is not used for this purpose many parts of the devices will call for the use of steel. Corrosion could be a big problem with this material, but the vast find of knowledge and experience in the use of corrosion resistant coatings and cathodic protection which has been built up over many years in the shipbuilding industry suggests that this will not be a limiting factor. Ships with good coating systems now expect at least four years between dry docking and much longer between major repairs to anti-corrosion coatings, and this type of work could be done when the wave energy stations have to be taken off line for maintenance or refit.

New paints for application to wet surfaces are also being developed and the wave energy programme should benefit from this work.

Another problem with steel is fatigue failure. Not much is known, as yet, about this and the Department of Energy supports a major research programme to provide quantitative data for the assessment of the safety and reliability of steel in offshore structures (the U.K. Offshore Steels Research Project).

Other materials considered for use with wave energy devices are rubber and glass reinforced plastics.

Rubber will be a necessary part of many of the devices, in the hinges of the Rectifier's flap gates for example. Glass fibre has been used in the building of small boats for quite some time and although there may be a strength loss due to moisture and dynamic fatigue over time, designs could make use of low working stresses to produce structures which are durable and resistant to creep. More work is needed on these materials and a Technical Advisory Group has been set up to deal with this (see Appendix II)

Marine fouling in the settlement and growth of marine plants and animals on any part of the marine structure. Included in this definition could be floating debris and seaweeds which may come into contact with the structure. The main problems associated with marine foulings include increased volume; increased surface roughness and drag; masking of surface to obviate routine inspection and maintainance; changes in corrosion fatigue behaviour; blockage of pipes, valves and gates etc.

To collect more data on the types of fouling to be expected at the prime wave energy sites off the Hebrides an experimental programme has been initiated. Harwell Laboratory and Scottish Marine Biological Association have jointly designed and built an experimental test rig 10 miles west of South Uist. This is being used to monitor fouling over 2 seasons.

Moorings are also a big problem, mainly due to costs. The development of wave energy converters could probably proceed unhindered for quite some time using over designed mooring systems but this would be very wasteful.
Preliminary work in 1978 by the engineering consultants to the WESC indicated that moorings could compose a substantial proportion of the total costs of a wave energy device, therefore reliability, to withstand the most severe storms, and costs are the most important consideration in design.
To this end a Technical Advisory Group has been set up to look specifically at the problems of moorings and to provide expert knowledge to the WESC and the device teams.
Transmission of energy form the wave energy converter to the places where it is needed poses one of the biggest problems. Submarine cables will have to be used to bring the electrical energy from the devices several kilometres out at sea, to the mainland. This is assuming that electrical transmission is the method that will be used. Many others including chemicals have been suggested.
With the development of a.c. to d.c. converters it is possible to supply energy with either alternating or direct current.
At present d.c. is preferred, as far as submarine cables are concerned, as distance does not present a great problem.
Peak power transmission by high voltage a.c. submarine cable is limited by several factors:- Cable changing current; Operating power factor; Voltage drop (approx. 15% maximum); Conductor size; thermal rating when fully submerged.

Up until recently the commonly accepted limitation of distance with 132 kV (typical transmission voltage for a 200/400 MW generating station) a.c. transmission by uncompensated oil impregnated paper insulated cables was 35 km.

With the introduction of XLPE insulated cable power transmission is now feasible up to 100 km.
Hopefully the next development will be flexible a.c. cables capable of carrying 132 kV and being flexed without electrical breakdown.

There are obviously many other problems, I have covered only a few, but with continued work by the Technical Advisory Groups and experience with offshore oil and gas production I hope we will soon find solutions to many of them.

5. In Conclusion

The ultimate measure of wave power viability is 'pence per kilowatt hour'. The Department of Energy has twice commissioned consulting engineers Rendel, Palmer and Tritton to cost the wave devices in its programme. The first exercise reported in December 1978 came up with costs of between 30p and 50p/kWh for five devices. This figure was unduly high due to over compensations made for the unknown areas of development of these converters. In December 1979 the costs for a 2GW station had come down to about 5.15p/kWh, many of the device teams are now claiming to be within a penny or so of the 3 - 4p/kWh target.

Since 1976 the Government has spent some £13 million on the wave energy programme.

In 1975 the aim of the programme was said to be 'a prototype device by 1986, and a full scale demonstration by the 1919's'. It was always possible that the Government would not take the programme this far but with costs, from official sources, nearing the target of 3 - 4p/kWh there seemed to be hope. 1982 was 'decision time' with most of the work due for completion and contracts coming up for renewal.

Then on April 27th, 1982 came a report by the Department of Energy from ACORD "Summary of Advice to the Secretary of State for Energy on His Research and Development Programme on Renewable Energy Sources". Under the section on wave power came this recommendation - No new development work on wave power should be supported from the Departments research and development budget : However a detailed comparison of the major systems was planned for September 1982 when most of the present work is scheduled for completion.

The existing contracts should be allowed to run their course. The results from all the projects should be prepared for publication by the Department. It was important, in the Council's view, to present the results in a tidy form so that the work supported to date would be available to Government or private sector should it be decided to reconsider the role of wave power in the U.K. economy. If necessary limited funds should be made available to support this activity. The Council recommended that if the budget did not permit both the existing contracts to run their course and the results of the work to be prepared for publication, priority should be given to the latter".

So it would seem that wave energy is to be shelved by the end of this year. There is talk of sales of U.K. wave technology and expertise to the Japanese.

Having already built an experimental wave device, a ship Kaimei 18m long and 12m wide, with their experience and knowledge of ship building and their lack of many other fuel resources firing their determination I do not think it will be long before we see a device of British origin in Japanese waters.

Hopefully the more determined of the British contenders will continue under their own steam.

Hopefully this is not the beginning of the end but only the end of the beginning.

A P P E N D I X   I

BRITISH PATENTS ON WAVE-POWERED DEVICES 1855-1973

1855-1908 Class 69 - 'Hydraulic Machinery'. Sub-classification: 'Wave Mills'.

Year(s)	Patent No(s)
1855	2541
1857	2765, 3060
1859	341
1860	139, 594
1861	1557
1862	654
1863	2288
1864	630, 2779
1865	3232
1866	126
1867	11, 266
1868	847
1869	346, 2632, 3680
1870	3117
1871	1083, 1883, 1958, 2866, 3190
1872	142, 452, 3031, 3761
1873	1361, 1706, 2583, 2807, 3735
1874	816, 2687, 3051, 3629
1875	308, 2890, 4148
1876	2011, 2286, 3585, 3956
1877	1794
1878	1557, 3016
1879	2713, 4640
1880	1382
1881	2983, 3563, 4192
1882	1659, 3827, 5276
1883	2274, 4187
1884	1528
1885	11,990, 15,085
1886	2049, 7298, 10,174, 11,636
1887	7247
1888	17,593
1889	15,696, 20,673
1890	8947, 15,748
1891	11,928, 12,587, 14,488, 19,140, 21,530, 21,531
1892	8051
1893	12,045, 13,212, 15,882, 15,943
1894	9451, 11,642, 13,152, 16,930, 22,628
1895	14,630, 16,650, 23,920
1896	8284, 20,972
1897	8218, 9016, 20,543, 24,064, 24,336
1898	225, 4311, 7555, 19,681, 21,403, 21,870
1899	5934, 6335, 6697, 9762, 10,444, 11,115, 13,281, 15,488, 19,999, 25,572
1900	863, 3322, 5465, 6260, 11,215, 12,463, 21,361
1901	12,339, 23,826, 26,613
1902	3257, 3714, 25,646
1903	2942, 3741, 4002, 8731, 13,986, 14,485, 18,773, 23,284, 28,484
1904	2371, 5386, 9359, 12,099, 12,343, 18,599, 27,050, 27,050A, 27,050B, 27,050C

Year(s)	Patent No(s)
1905	166, 3590, 5065, 12,436, 19,896, 25,494, 27,070
1906	2999, 5058, 8184, 13,185, 21,340, 25,984, 26,812
1907	1668, 7173, 9106, 9279, 10,720, 16,891, 18,918, 19281, 21,266 27,313, 27,949, 28,037, 28,591
1908	3673, 8739, 11,437, 12,573, 14,532, 14,533, 14,778, 19,608

1909 Change of classification to: Class 69(1) 'Hydraulic Machinery'. Sub-classification: 'Wave and Tide Energy Utilizing'.

Note In the patents from 1909-1925 no division is made between wave and tidal machines. The following patents therefore include purely tidal devices as well as devices which derive their power purely from wave action and also devices which can utilize either tidal or wave movements or a combination of both.

Year(s)	Patent No(s)
1909	956, 2854, 3164, 3844, 8116, 11,716, 22,015, 22,725, 28,592
1910	8283, 20,161, 21,336, 25,318, 25,833, 27,708
1911	7087, 9231, 12,232, 16,372, 19,115, 19,128, 21,239, 27,049, 28,952
1912	8857, 9040, 11,731, 17,595, 18,101, 28,343, 28,982
1913	1226, 1625, 4994, 5788, 12,259, 15,279, 16,106, 24,018, 28,014, 29,887
1914	139, 1544, 3691, 8503, 16511, 18051, 19,948, 20,415
1915	12,354, 12355
1916-20	100,461, 101,916, 102,980, 104,157, 106, 027, 109,353, 112,554 116,372, 117,340, 118,989, 121,386, 121,831, 122,229, 122,706 125,226, 126,573, 127,154, 128,399, 132,313, 136,733, 136,952, 138,590, 139,319, 140,573, 144,358, 146,611, 147,720, 148,357, 150,264, 152,360, 152,484, 154,054, 154,188
1921-25	156,248, 156,315, 157,215, 158,048, 158,368, 158,661, 158,971, 161,295, 163,636, 165,789, 166,739, 167,777, 170,429, 171,104, 171,346, 172,078, 174,467, 174,505, 175,152, 175,928, 177,576, 181,744, 183,826, 185,515, 188,330, 188,812, 190,743, 191,239, 191,780, 193,146, 194,918, 196,017, 196,660, 197,002, 200,559 202,709, 203,435, 203,860, 205,846, 209,126, 209,598, 209,871, 210,228, 210,461, 213,492, 214,188, 218,102, 219,323, 223,374, 226,786, 228,513, 228,631, 228,914, 230,296, 235,508, 236,652, 237,807, 238,337, 241,760, 244,418

1926-1930

Note The patents from 1926-1963 were examined to determine whether their operational principle depends on wave-action, tidal action or both. A (W) indicates a device based purely on wave derived energy, (T) a purely tidal device and (WT) a scheme which in theory is dependent only on a variation in level and can operate from wave or tidal movements. An (I) has been used where the principle of operation could not be easily determined from the relevant abridgement.

1926-30	264,772W, 265,094W, 266,621I, 267,387WT, 267,945T, 269,316T, 273,219T, 275,115T, 277,007W, 277,888W, 283,327T, 283,607T, 291,265W, 292,314W, 292,906T, 293,925W, 296,330I, 297,288W, 297,569WT, 297,720W, 301,264W, 302,546WT, 305,477T, 307,681W, 336,209I

1931 Change of classification to: Group XXIX Sub-classification: 'Wave and Tide Energy Utilizing'.

Year(s)	Patent No(s)
1931	344,374I, 346,947W, 348,672I, 349,103I, 349,260T
1932-33	384,603W, 384,844WT, 385,909W, 386,818W, 398,280W
1934-35	424,881W
1935-37	456,672W
1937-38	464,317WT
1938-39	487,850T
1939-40	511,809T, 519,155W
1940-41	525,069W, 530,898TI
1941-44	541,775W, 557,049W
1944-46	562,285W, 566,396W, 566,691W
1946-48	590,196W, 590,331T
1948-49	612,175W, 613,159W, 613,160W
1949-50	628,278W, 628,422W, 633,983W, 636,003T
1950-51	655,987W
1951-52	677,186W
1952-53	681,639W
1953-54	710,685T, 717,112T
1954-55	734,294W
1955-56	741,494W, 745,084W, 750,602T, 757,686W
1956-57	Nil
1957-58	789,044WT
1958-59	801,263W, 801,264W, 801,984W, 807,281W, 810,405T
1959-60	826,431W, 831,518T
1960	845,110W, 857,242T
1960-61	Nil
1961-62	883,813W
1962-63	905,446W, 914,997W
1963	Nil

1963 Change of classification to F1 S28, 'Prime Movers, Utilizing Wave and Tide Energy'.

Note Patents from 1963 to 1973 were examined to separate wave powered devices from tidal; only those operating on wave power are listed below.

1963-64	940,823, 954,962
1964	Nil
1965	989,640
1965-66	1,014,196, 1,024,536
1966	Nil
1966-67	Nil
1967-68	1,099,977
1968	1,116,689
1968-69	1,130,107
1969	Nil
1969-70	1,176,559
1970-71	Nil
1971	Nil
1971-72	1,255,215
1972	Nil
1972-73	Nil

Note In the above list of patents the years referred to are the years indicated on the volumes of patent abridgements. This is not necessarily the data ascribed to the patent.

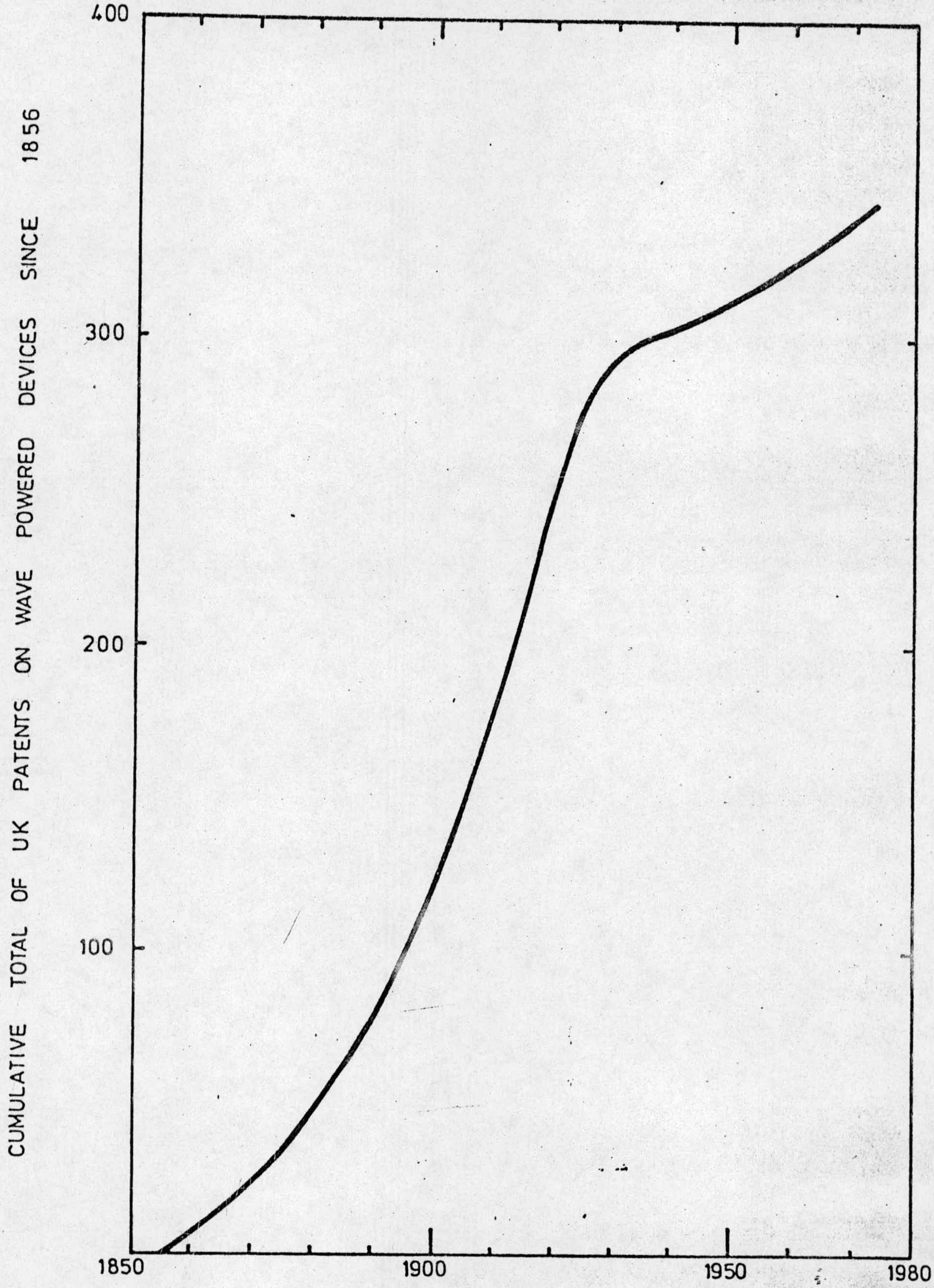


FIG.I GROWTH OF UK PATENTS ON WAVE POWERED DEVICES.

TABLE I

WAVE POWERED GENERATORS - SUMMARY OF DEVICES BUILT AND TESTED UP TO OCTOBER 1974

	Year	System	Power	Location	Organisation / individual } concerned	Remarks
1	1910	Vertical bore hole in cliff oscillations in water level driving an air turbine	1 kW	Royan, nr Bordeaux, France	M Bochaux-Praceique	Supplied entire power and light for dwelling house
2	1911	Pier structure with floats using both vertical and horizontal motion	110 kW	Young's 'Million Dollar' Pier, Atlantic City, New Jersey, USA	US Wave Power Company	Power level claimed, but not substantiated on investigation
3	1920	Float system operating in a basin connected to sea	n.a.	Algiers, N Africa	M Fusenot	Feeble power level
4	1926	Not identified	-	Minou lighthouse, Brest, France	M Coyne	Discouraging results
5	Pre 1931	Savonius rotor	n.a.	Baltic Sea	J Savonius	Limited trials
6	Pre 1931	Savonius rotor operating pump	up to 7 kW	Musee Oceanographique Monaco	M Richards	Rotor driving double acting pumps lifting water to a height of 200 ft
7	1931	Heavy float rising and falling to operate pump		Musée Oceanographique Monaco	F Cattancao	Operated 10 years pumping water destroyed by heavy seas

n.a. = not available.

TABLE I (cont.)

	Year	System	Power	Location	Organisation / individual } concerned	Remarks
8	Pre 1944	Converging channels supplying a fore bay for a low head station	n.a.	i Pointe Pescade ii Sidi Ferruch Algeria	i Societe Mediterranéenne d'Energie Marine ii Societe Marocaine d'Etudes de la Houle et du Vent	Qualatative study with encouraging results
9	1944	Model of above	n.a.	-	Laboratoire Dauphinois Hydraulique	Technically successful concept but not economically viable
10	1947	Three float system	200 W	Japan	Y Masuda, Oceanographic Unit, Japanese Maritime Self-Defence Unit	Tests abandoned after device overturned by high wave.
11	1957-59	Hydraulic system	1 kW	Japan	Y Masuda	Test failed
12	1960-63	Air turbine-fixed system	500 W	i Kannonzaki, nr Yokosuka harbour, Japan ii Institute test tank	Masuda supported by R & D HQ of Japan Defence Agency	
13	1962	Submerged buoy with diaphragm activated generator	0.25 W	Buzzard's Bay, Massachusetts	AVCO Corporation (RAD) Division	Tests carried in sheltered location with no effective swell. Diaphragm ruptured in hurricane

n.a. = not available.

TABLE I (cont.)

	Year	System	Power	Location	Organisation / individual } concerned	Remarks
14	1963	Air turbine system in fixed pipe	n.a.	Nakaminato Rock, Pacific Ocean, Japan	Y Masuda supported by R & D HQ of Japan Defence Agency	Test safety of fixed air-turbine system in high waves
15	1963-65	Pendulum-type buoy	2-3 W	Japan	Nichiro Kogyo Kaisha Ltd Ryokuseisha Corporation funded by Foundation New Technique Development Corporation	Based on a suggestion and research of Y Masuda, was developed as a navigation buoy. Rejected because of sway effect on light
16	1964	'Ocean motion harness' operating on principle of self winding watch	n.a.	USA	Hamilton Watch Company Industrial and Military Products Division	Prototype weight 1 lb 3 in dia x 3 in high
17	1965-present	Air-turbine buoys	100 W	Japan, USA, UK	Invented by Y Masuda Patented and manufactured by Ryokuseisha Corporation UK agents: Sumitomi Shaji Kaisha Ltd	Over 300 buoys now in operation off Japan, USA, Canada, Persian Gulf, and British Isles, Tested by Irish Lights 1970
18	1966	Air turbine fixed system adapted to power lighthouse		Ashika-jima Lighthouse, Tokyo Bay, Japan	Customers: Japan Maritime Safety Board Suppliers: Ryokuseisha	
19	1967	Wave-powered device to move sand	n.a.	USA	Coastal Engineering Research Centre	Device found to be unsatisfactory
20	1970	Air turbine generator	500 W	Expo 1970, Osaka, Japan	Y Masuda	

n.a. = not available.

TABLE I (cont.)

	Year	System	Power	Location	Organisation / individual } concerned	Remarks
21	1970	Hydraulic pumping over pliable strips in concrete trough	n.a.	USA	Power Systems Company, Boston, Mass, USA	Small scale tests successfully made
22	1970	Bobbing buoy with direct generation of electricity from linear generator	Less than 1 W	UK exhibited at 1970 Lighthouse Conference	Invented and patented by University College of N Wales.	Manufacturers dropped development after tests gave very low output
23	1971-2	Investigation of new construction method for air-turbine fixed method	n.a.	Japan	Y Masuda. Japan Electric Machine Association	
24	1970 - present	Wave pump device fitted to ship R V Ellen B Scripps	60 W (no turbine)	Tested off Point Conception, California, USA	i David Castell/Scripps Institute of Oceanography, La Jolla, California, USA ii Glosten Associates	First experiment July 1972 terminated because of pipe failure. Latest experiment reported July 1973 plagued by calm seas
25	1972 - present	Float with propellors on shaft	n.a.	Sweden	Fagersta A B, Sweden M Gustaffson, K J Loqvist	Experiments carried out on ½-m dia float
26	1973 - present	Oscillating vane device	Model	UK	S Salter, Department of Mechanical Engineering, Edinburgh University	Model tests have shown that 90 per cent conversion efficiency is possible
27	1973 - 1974	Model wave energy converter		USA	A D Little Inc. Test under contract for US firm	Device found to be of low efficiency

n.a. = not available.

TABLE I (cont.)

	Year	System	Power	Location	Organisation Individual concerned	Remarks
28	1974	Float with impeller on shaft	n.a.	UK	National Physical Laboratory	Subject of patent application through NRDC
29	1974	Various float devices	n.a.	UK	Wave Power Ltd	
30	1972-present	Autobailer wave-powered bilge pump	0.025 gal/min	Sweden	Imported by Yachtex, Westcliffe-on-Sea	Commercially available

n.a. = not available.

APPENDIX II TECHNICAL ADVISORY GROUPS

TAG 1 - NEW DESIGNS

Terms of reference

1. To review the fundamentals of wave motion in relation to the principles of wave energy extraction and, where thought appropriate, either to encourage and/or support current fundamental research work or promote such work particularly on basic principles not covered by the current WESC or SRC programmes.
2. To review on behalf of WESC all ideas and applications for financial support for new designs of wave energy converters submitted to the Department of Energy, and to make recommendations for action.
3. To recommend and initiate work on generic concepts associated with the fundamental principles of wave energy converters including aspects of current designs, drawing on resources of expertise available from the wave power programme as a whole.
4. To liaise with SRC in respect of research at universities on wave energy devices.
5. To keep informed on new international developments and to assess their relevance to and implications for the UK programme.

TAG 2 - WAVE DATA

Terms of reference

To determine what wave data are needed by the engineering development teams and what is required by other Advisory Groups and to arrange for such data to be provided if it already exists. If there are requirements for additional data the group will propose programmes of work to acquire such data.

TAG 3 - STRUCTURE AND FLUID LOADING

Terms of reference

1. Examine loading and structural design aspects of proposed converters, consulting with Device Teams as necessary.
2. Advise the Wave Energy Steering Committee, and where appropriate the Device Teams, on the problems of wave action and structural design.
3. Advise the Steering Committee on structural adequacy and efficiency of proposed converters, making recommendations where appropriate for improvements to structural design.

4. Evaluate programme of development work being carried out by the Device Teams, initiate and monitor on behalf of the Steering Committee any supplementary R and D which may be necessary to ensure the accurate prediction of wave-induced loads and mooring forces and efficient structural design.

TAG 4 - MOORING AND ANCHORING

Terms of reference

1. To advise on the suitability of present mooring and anchoring systems to the requirements of various wave power converters.
2. To advise Device Teams on technology specific to their designs, and to make recommendations on research and development requirements.
3. To recommend, instigate and monitor research and development programmes of a generic nature on behalf of the Wave Energy Steering Committee.

TAG 6 - GENERATION AND TRANSMISSION

Terms of reference

1. To identify possible energy conversion, generation and transmission systems.
2. To estimate the performance and cost of the more promising systems and make a first order assessment of the impact of the operational and performance (transfer efficiency) characteristics of particular designs on the overall economics of converters.
3. To provide design information for the teams developing particular converters.
4. To estimate the timescales and the R and D effort required to implement particular designs.
5. To make recommendations to the Wave Energy Steering Committee on the most promising system(s) for development.

TAG 7 - ENVIRONMENTAL IMPACT

Terms of reference

1. To examine the possible environmental effects of large wave power stations on;
   (a) the morphology of the adjacent coastline;
   (b) the navigation of shipping;
   (c) the local ecological balance;

(d) the fishing industry;

(e) leisure activities;

(f) interaction with other activities, eg
Ministry of Defence, oil exploration, etc.

2. Bearing in mind the likely location of wave power stations, to develop an awareness of the impact of shore installations on areas of scenic beauty and of the availability of large amounts of energy in areas of low economic activity.

3. To consider environmental effects in geographical areas which might be used for Phase II of the development programme.

4. To report to the Wave Energy Steering Committee and to advise the Device Teams as required.

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